

The Use of Objective Measures with Cochlear Implants

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Disclosures

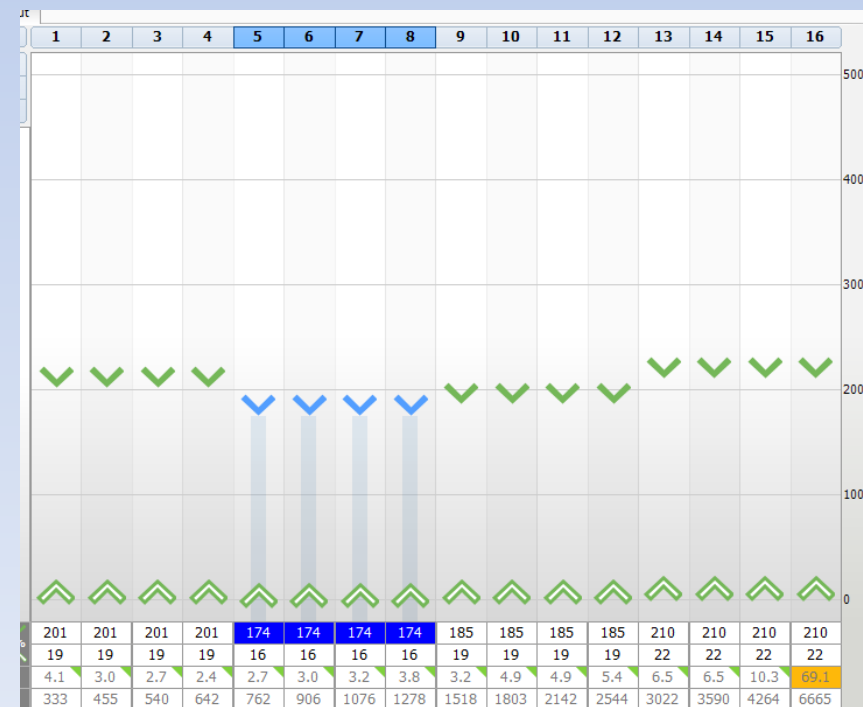
- Investigator for **MED-EL** IDE G040002 (EAS study) at BTNRH
- Research supported by NIH, NIDCD
 - **Cochlear, Advanced Bionics, and MED-EL** provide equipment on loan
- Member, American Academy of Audiology Clinical Practice Guidelines Task Force for Cochlear Implants

Introduction

- Programming (“mapping”) a CI involves subjective feedback:
 - Detection of electrical pulse trains (T-levels)
 - Most comfortable or upper comfort levels (C/M-levels)
 - Loudness balancing
 - Pitch ranking
 - Subjective preferences or speech perception to compare maps with different parameters (e.g., strategy type, stimulation rate)

Introduction

- What if you can't get that behavioral feedback or what you get is unreliable?
 - Monopolar stimulation:
 - Levels more uniform
 - Better for interpolation
 - Requires fewer behavioral responses
 - Objective measures



Introduction

- Objective measures are used to:
 - Verify device function
 - Verify auditory pathway function
 - Programming guidance when behavioral feedback is limited or absent

Introduction

- Most common objective measures:
 - Electrode impedance
 - Electrically evoked compound action potential (ECAP)
 - Electrically evoked stapedial reflex threshold (ESRT)

Electrode Impedance

- Measured via device's telemetry capabilities
- Informs of:
 - Short circuits
 - Open circuits
 - Voltage compliance
 - Atypical impedance

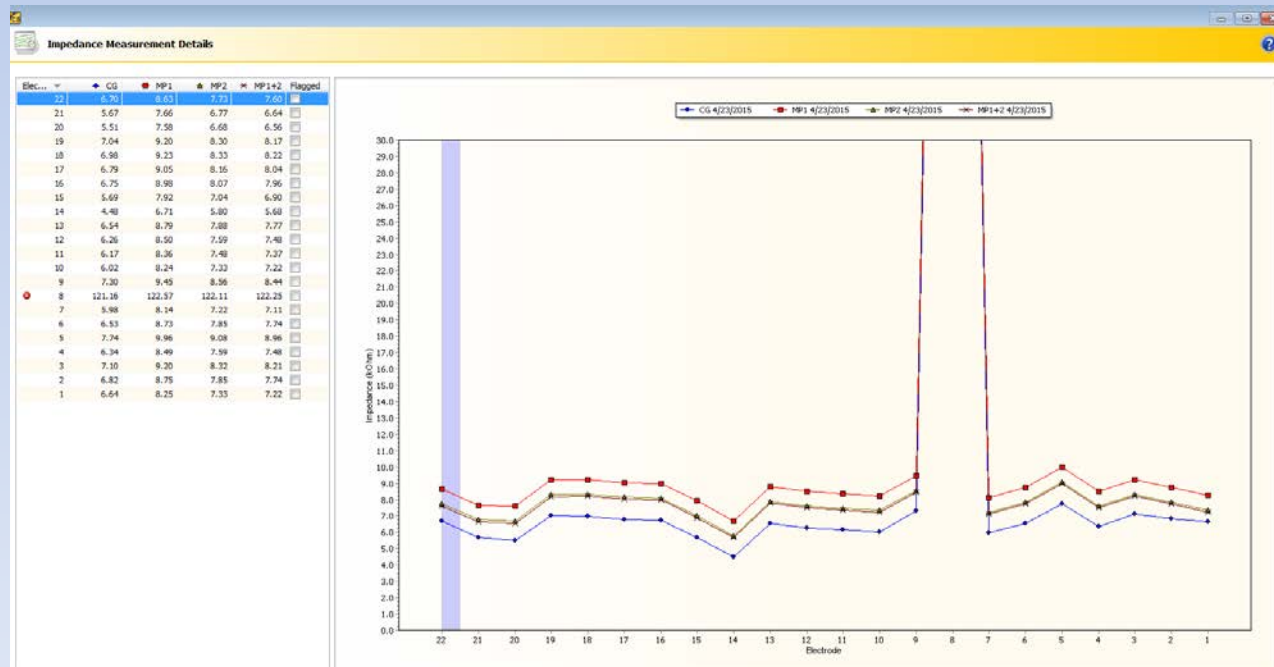
Electrode Impedance

- Possible consequences of including abnormally functioning electrodes in maps:
 - Non-auditory percepts
 - Poor sound quality
 - Pitch confusions/reversals
 - Reduced performance

Electrode Impedance

- Short/open circuits can be easily identified and flagged in the commercial software

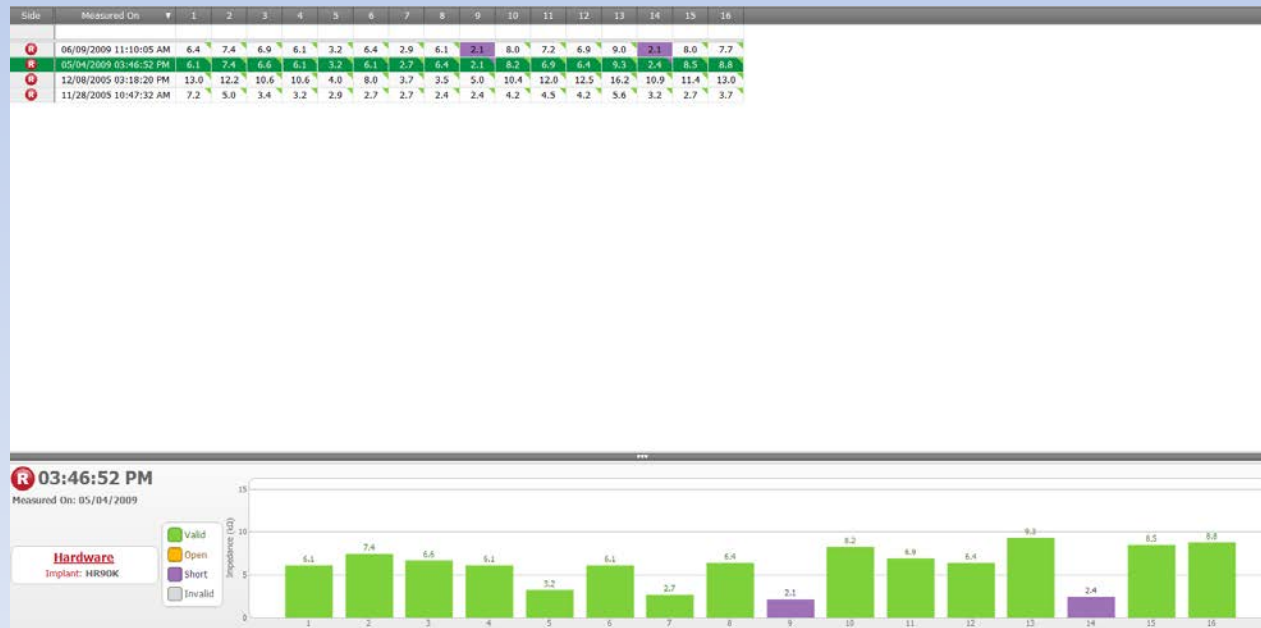
Open circuit in Cochlear's Custom Sound



Electrode Impedance

- Short/open circuits can be easily identified and flagged in the commercial software

Short circuit in Advanced Bionics' SoundWave



Electrode Impedance

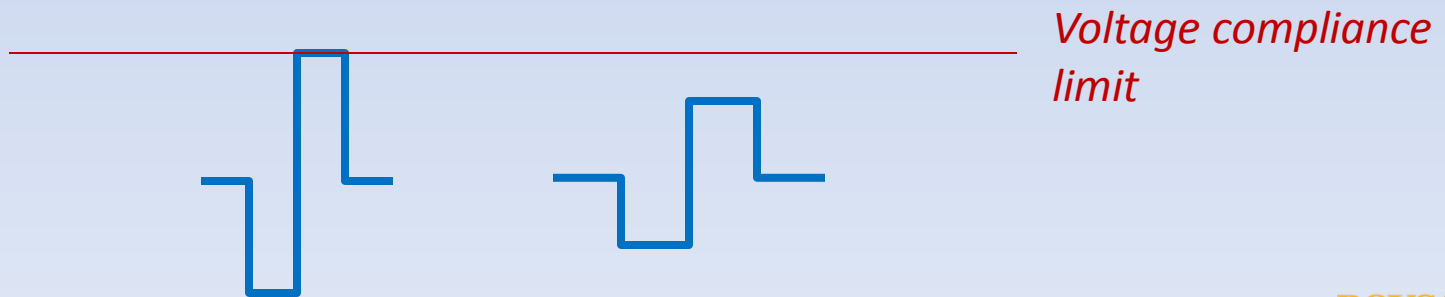
- Short/open circuits can be easily identified and flagged in the commercial software

Open circuit in MED-EL's Maestro



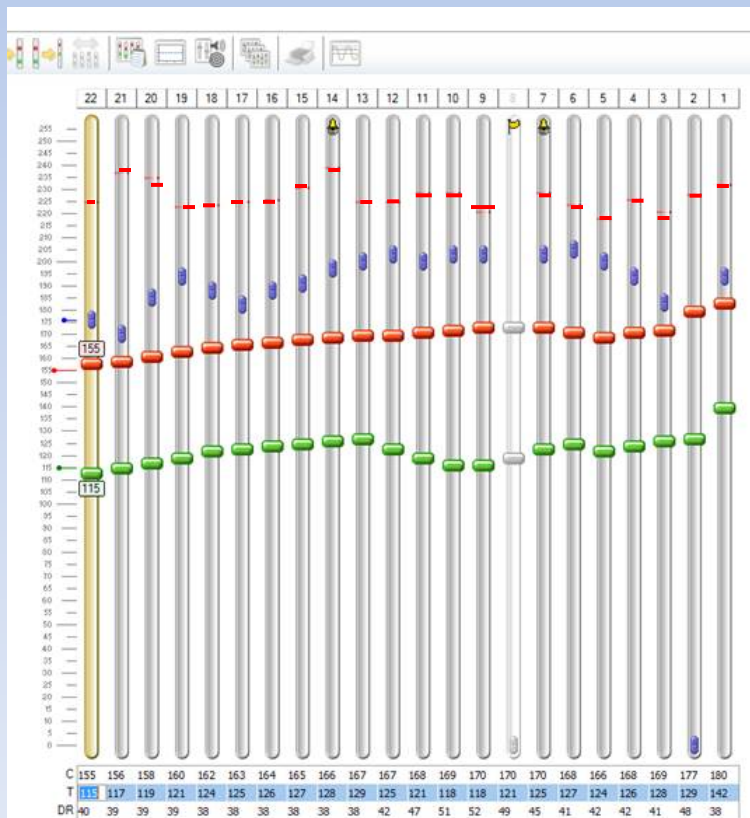
Electrode Impedance

- “Out of voltage compliance”
 - Ohm’s Law: $V=IR$
 - Insufficient voltage to achieve the current (amplitude) requested
 - Lengthen pulse duration so amplitude can be reduced for same overall charge



Electrode Impedance

- Voltage compliance not always flagged and not automatically limited



Comment: ---

Volume Mode: IBK 0 - 100%
 Default Volume: 100 %
 Frequency Bands: Logarithmic FS 100 - 8500 Hz
 Maplaw: Logarithmic Maplaw c = 1000.00
 Default Sensitivity: 75 %
 Strategy: FS4
 Compliance Level: 2

Band Assignment: 2 3 4 5 6 7 8 9 10 11 12
 AGC Compression: 3:1
 Auto Adjust: ☒

LED Signals: Battery Empty: ☒
 Fine Tuner: ☒
 Private Alerts: Warnings: ☒
 Status: ☐
 Confirmation: ☒
 Alert Loudness: 4

Channel Number	Channel Status	MCL [qu]	THR [qu]	Effective Duration [μs]	Min. Duration [μs]	Center Freq. [Hz]	Stimul. Rate [pps]	Comp. Limit [cu]	Channel Type
1	Globally Disabled	33.05	0.00	53.75	0.00	0	0	777	
2	Enabled	28.19	4.52	33.75	0.00	154	6452	885	CSSS
3	Enabled	28.49	4.24	33.75	0.00	278	6452	1006	CSSS
4	Enabled	34.99	3.77	33.75	0.00	448	6452	983	CSSS
5	Enabled	36.96	5.14	33.75	0.00	673	6452	1802	CSSS
6	Enabled	36.96	5.07	33.75	0.00	966	1290	1106	
7	Enabled	34.55	5.07	29.58	0.00	1406	1290	1079	
8	Enabled	31.54	4.92	29.58	0.00	1978	1290	1339	
9	Enabled	24.20	4.65	21.25	0.00	2714	1290	1164	
10	Enabled	20.54	3.90	21.25	0.00	3858	1290	1179	
11	Enabled	20.29	3.17	21.25	0.00	5238	1290	1041	

23.04.2015 16:23:33 Maestro 4.1.2 Build 4895.15716 1/2

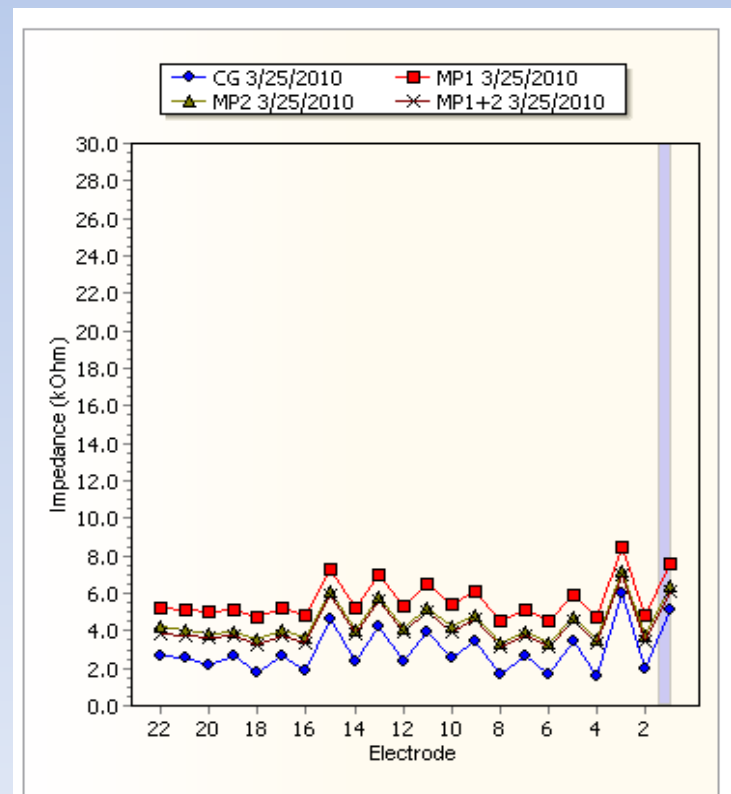
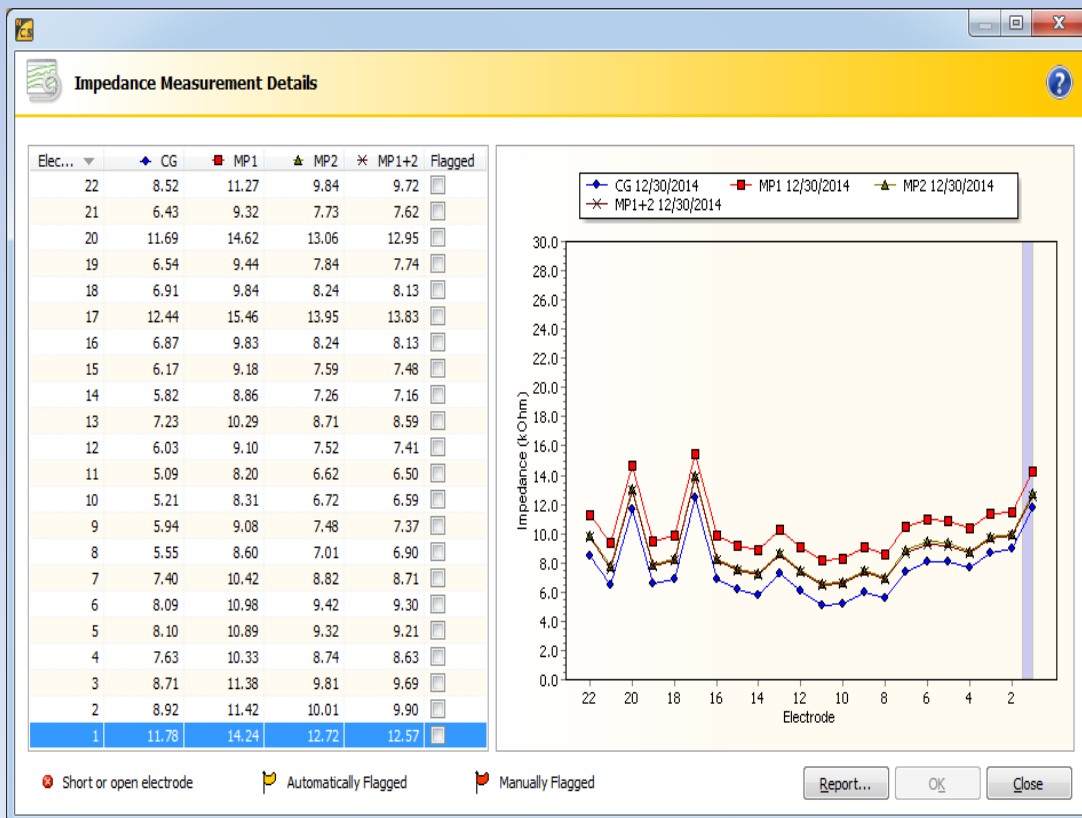
Electrode Impedance

Neuburger et al. (2009):

- Stimulating when OVC can result in:
 - Potential for asymmetric current pulses
 - Insufficient loudness growth
 - Further increases in impedance
- Recommend widening pulse duration to avoid OVC

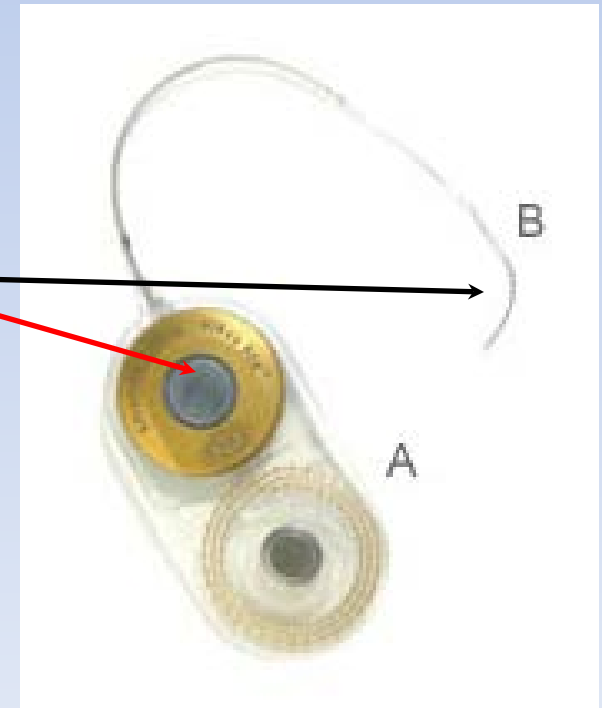
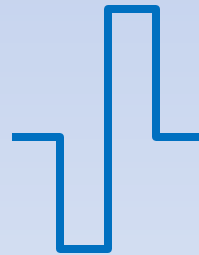
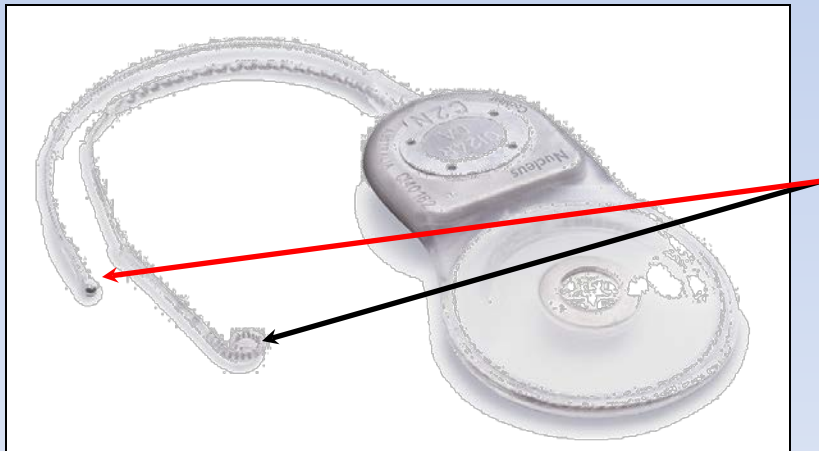
Electrode Impedance

- Atypical impedance requires longitudinal monitoring *(Cochlear Ltd. 2011; Cullington 2013)*



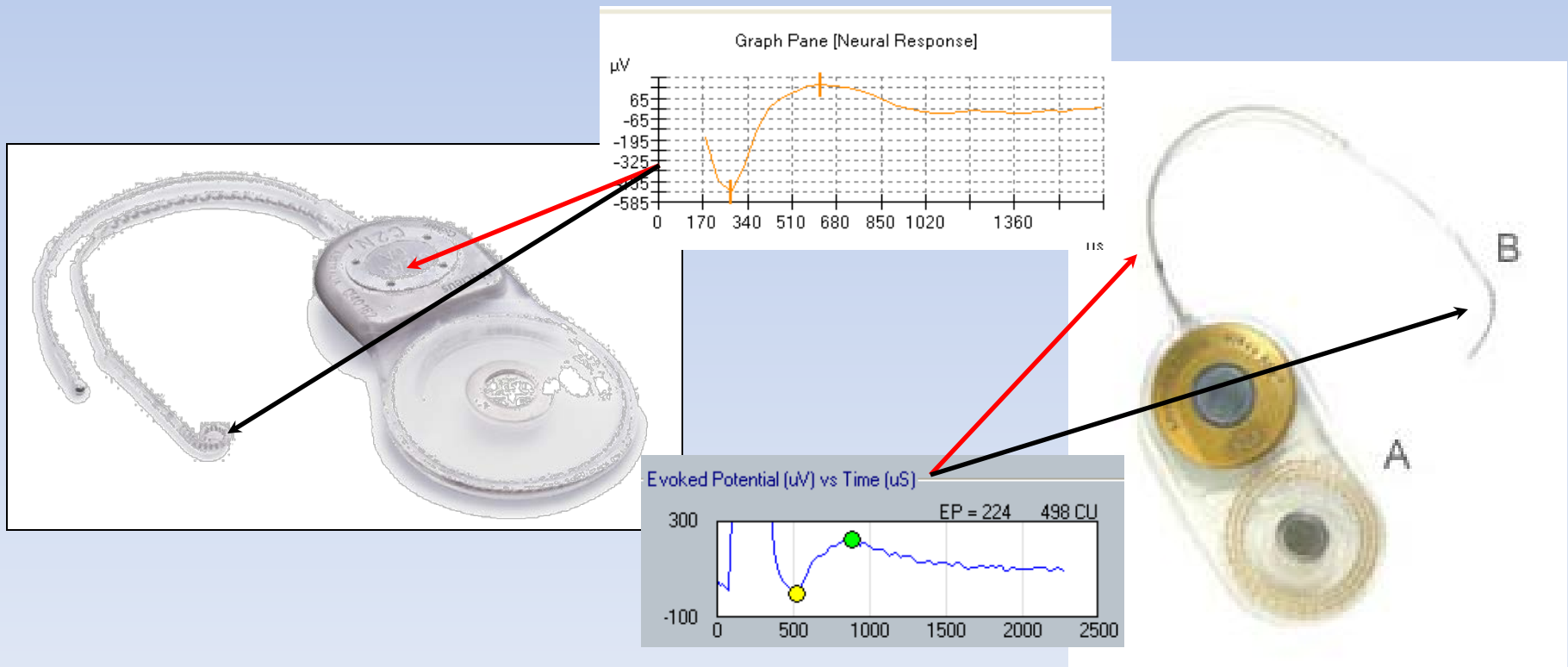
ECAP

- Measured via device's telemetry capabilities
- Aggregate response of auditory neurons



ECAP

- Measured via device's telemetry capabilities
- Aggregate response of auditory neurons



ECAP

- Informs of:
 - Device function
 - Auditory nerve function
 - Spatial excitation patterns (potential indications of electrode foldover)
- (Grolman et al. 2008)*

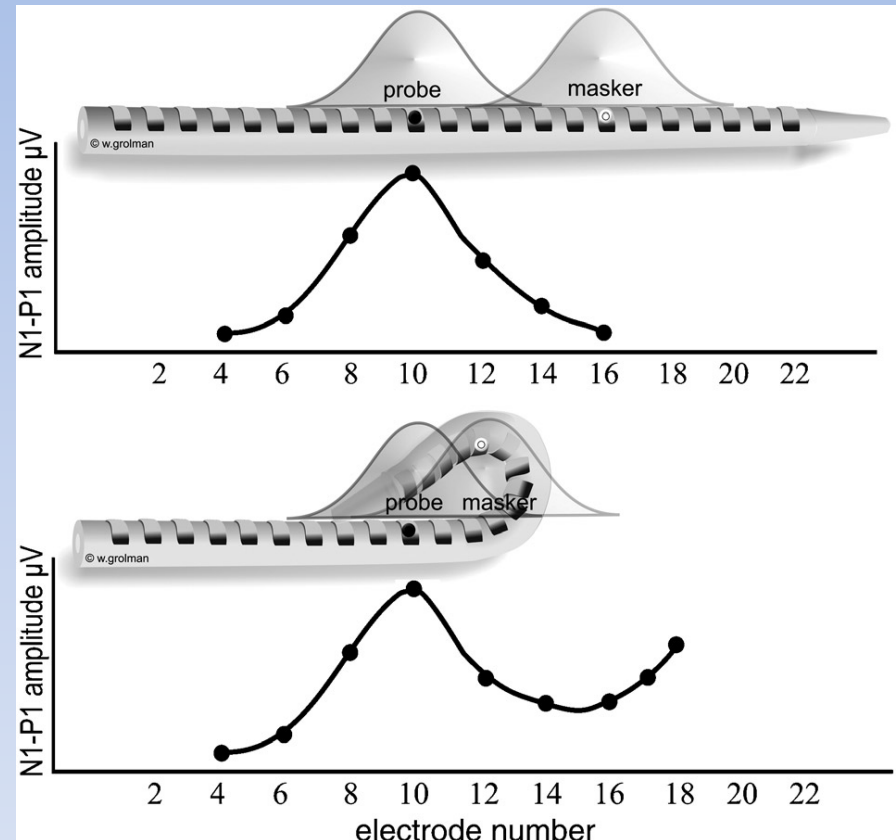
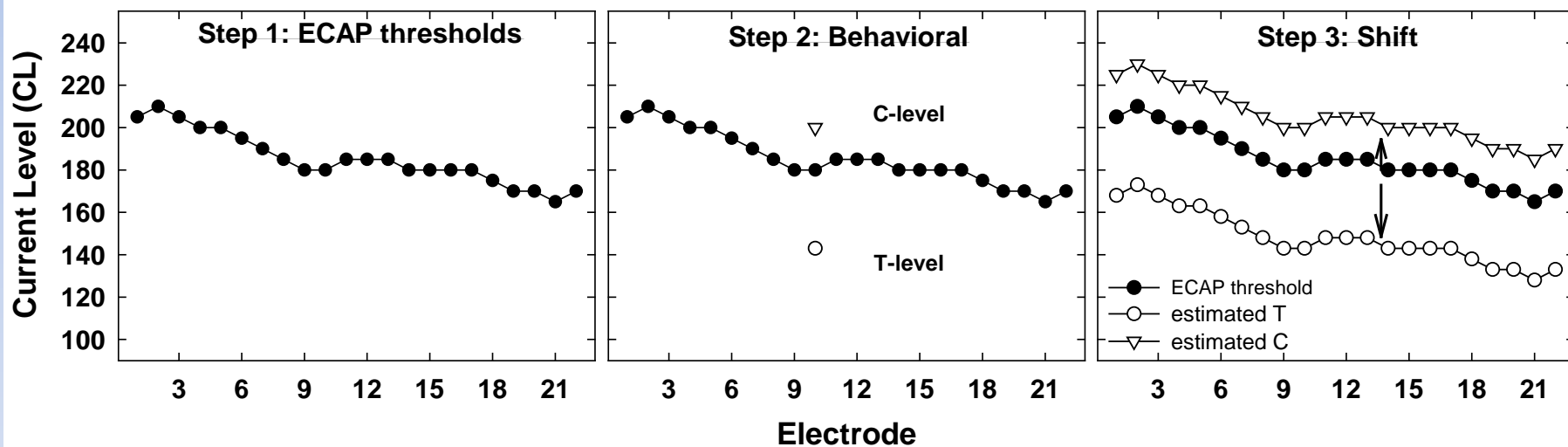


Fig. 2, Grolman et al. (2008)

ECAP

- Used to guide mapping



Brown et al (2000); Hughes et al (2000)

ECAP

- Used to guide mapping

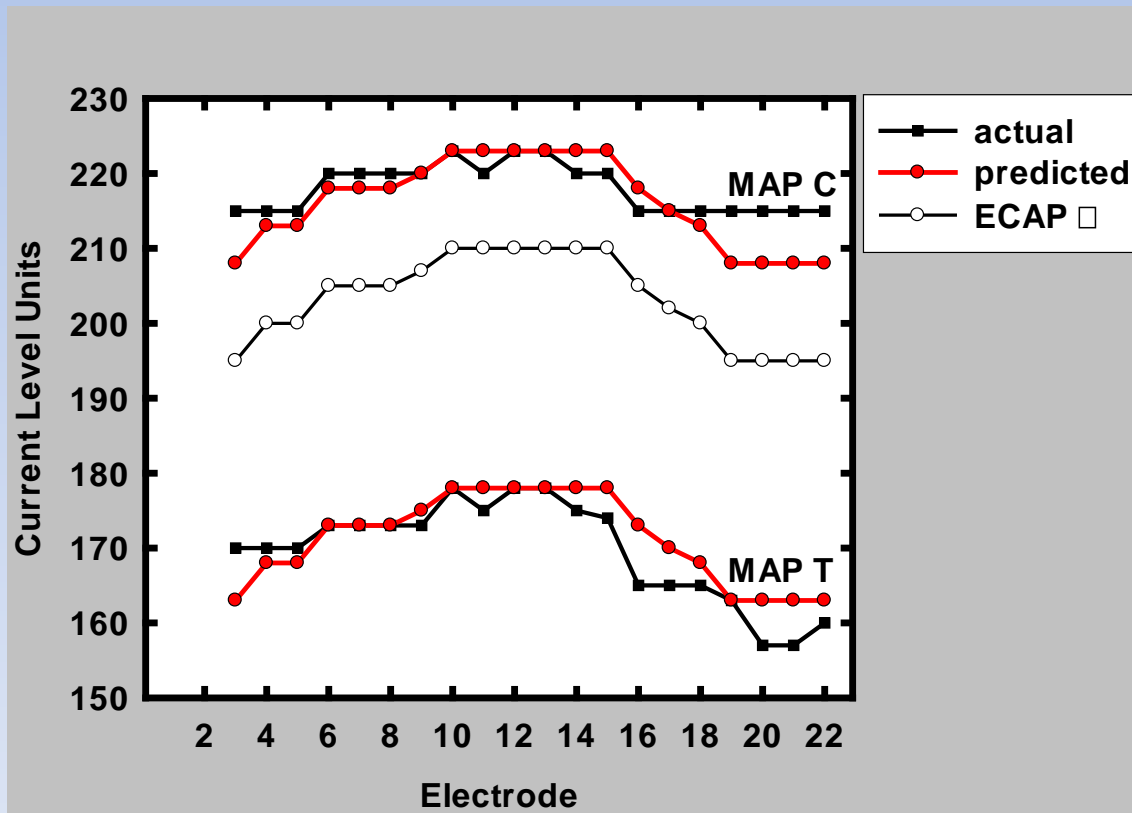


Fig. 3b, Hughes et al (2000)

ECAP

- But in some cases, ECAPs don't predict map profile:

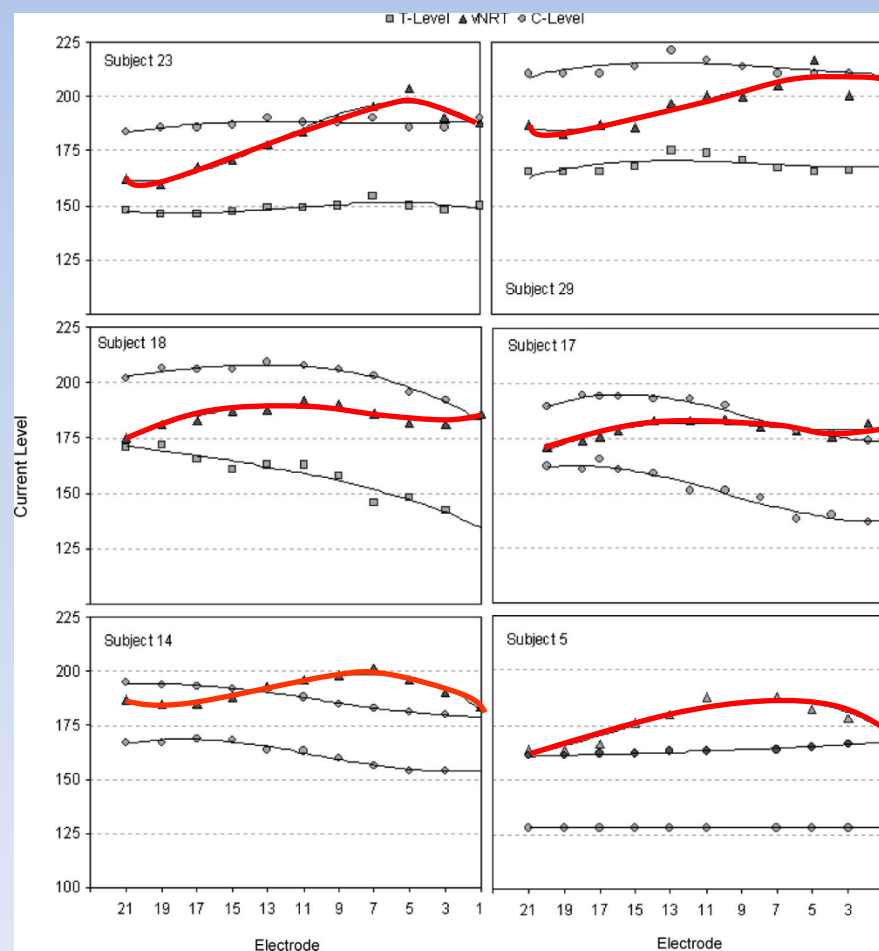
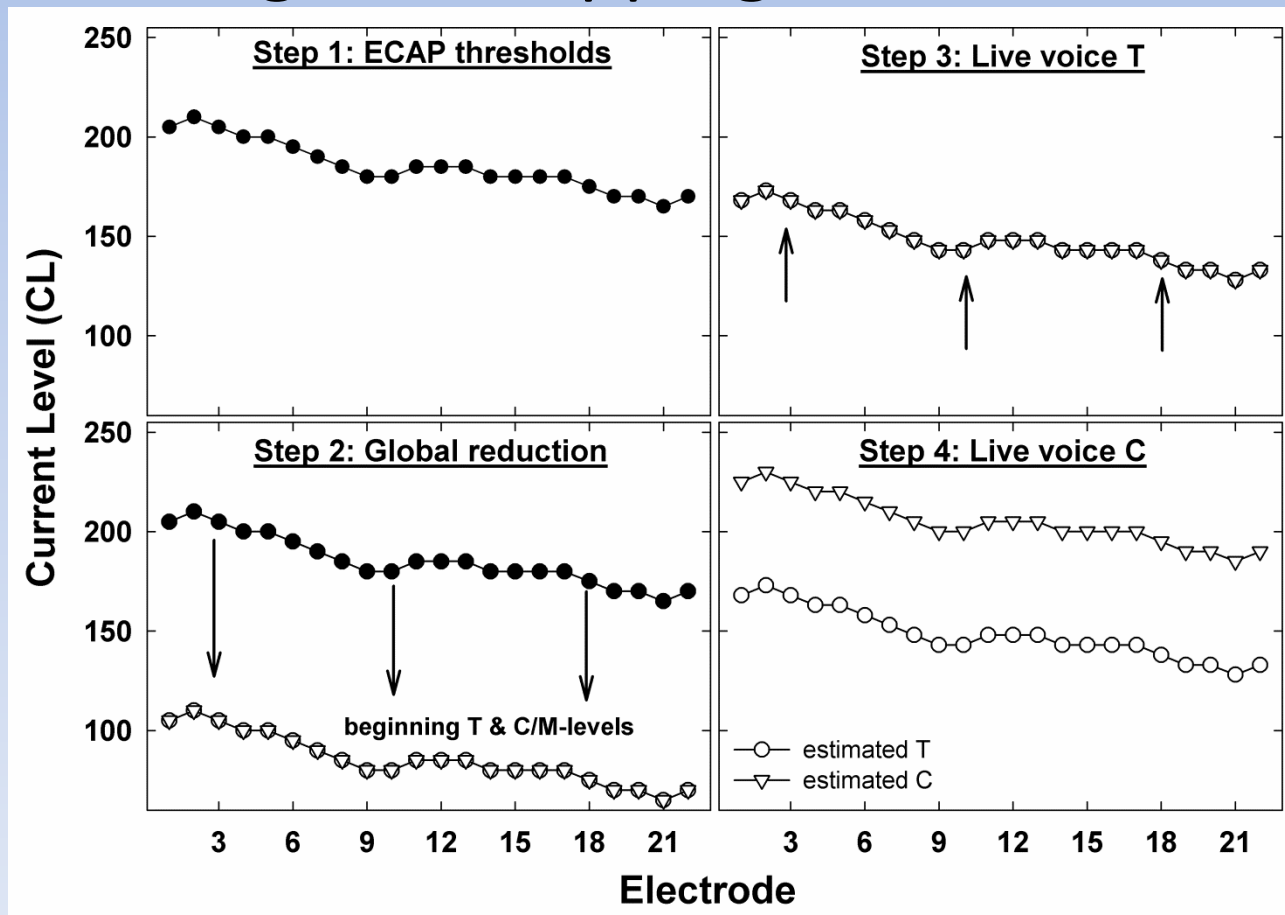


Fig 4, Holstad et al (2009)



ECAP

- Used to guide mapping



Smoorenburg et al (2002)

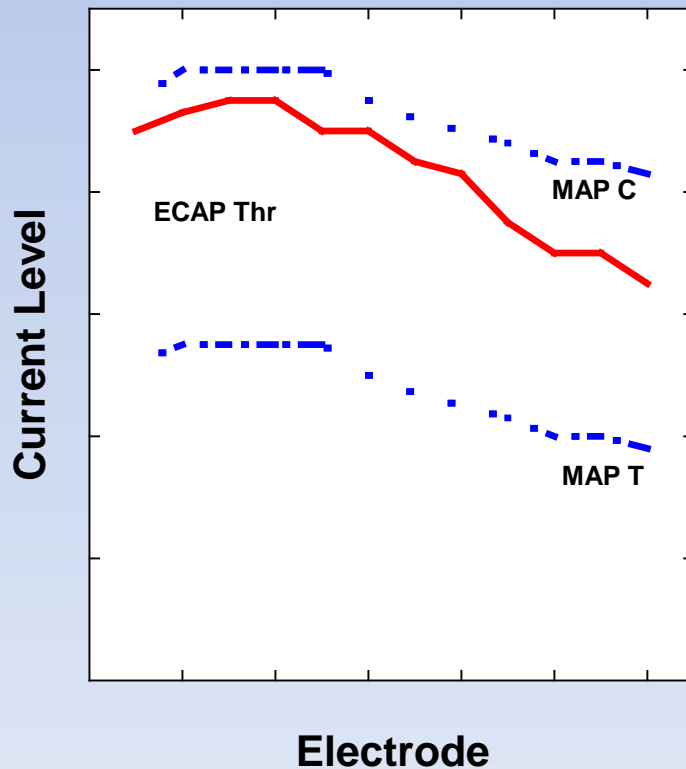
ECAP: Important Considerations

- ECAPs almost always fall above behavioral threshold
 - AUDIBLE
 - Starting point for conditioning for behavioral testing
- May fall within map dynamic range or above C/M. Contributing factors:
 - Map rate
 - How upper comfort levels are defined

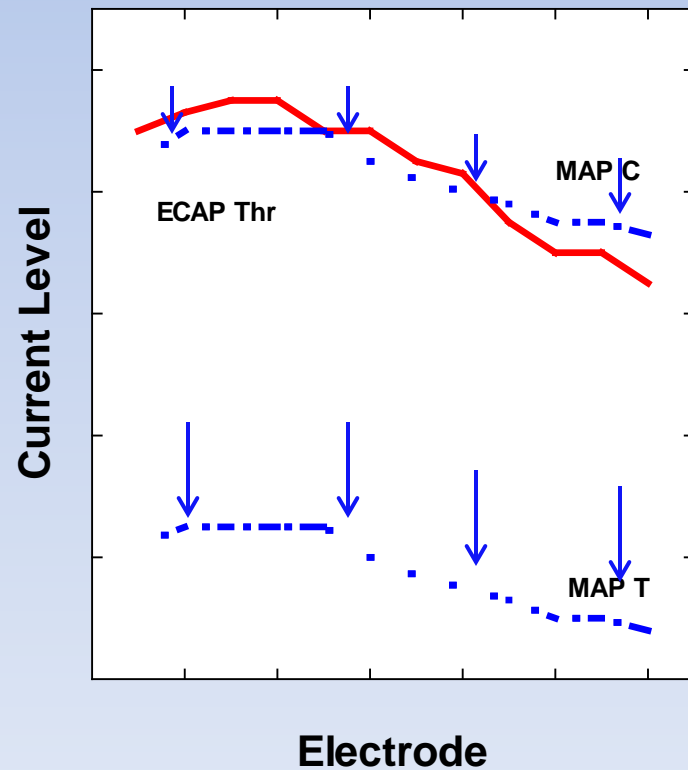
ECAP: Important Considerations

- Effect of map rate:

Slow Map Rate



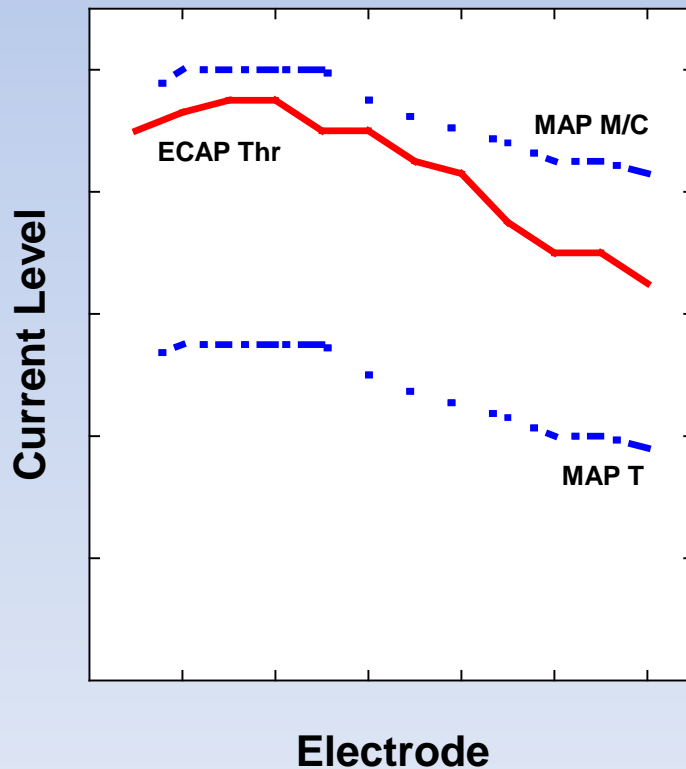
Fast Map Rate



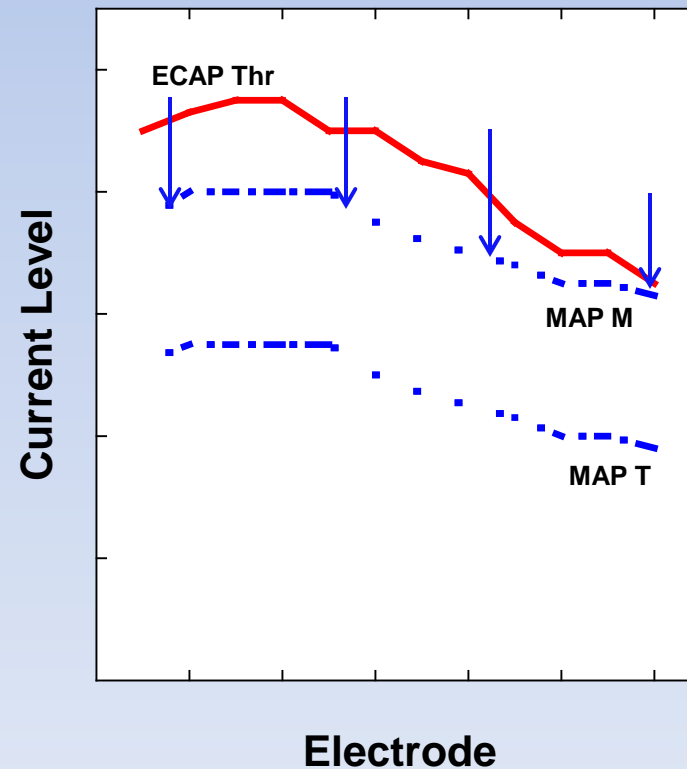
ECAP: Important Considerations

- Effect of how upper end of DR is defined:

Upper Boundary=UCL



Upper Boundary=MCL



ESRT

- Similar to acoustic counterpart; CI provides stimulus

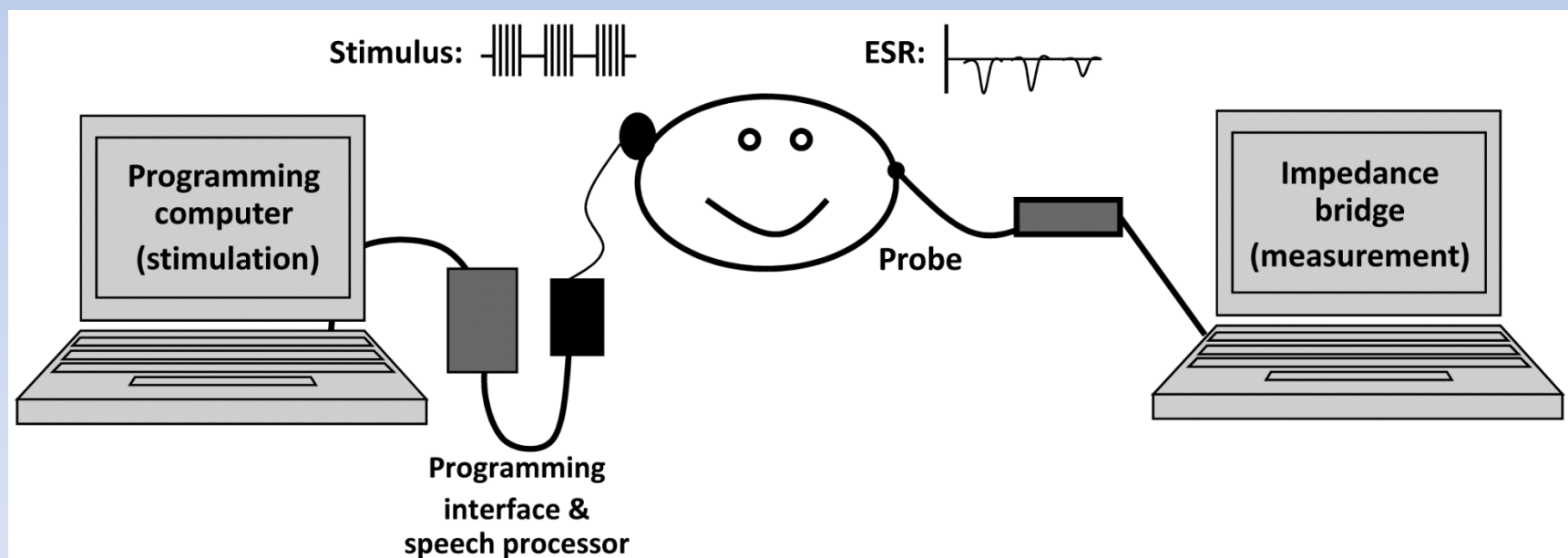


Figure 6-1, Hughes (2012)

ESRT

- Good correlation with upper comfort levels, but can also overestimate UCL.
- Again, upper limit of DR is defined differently.

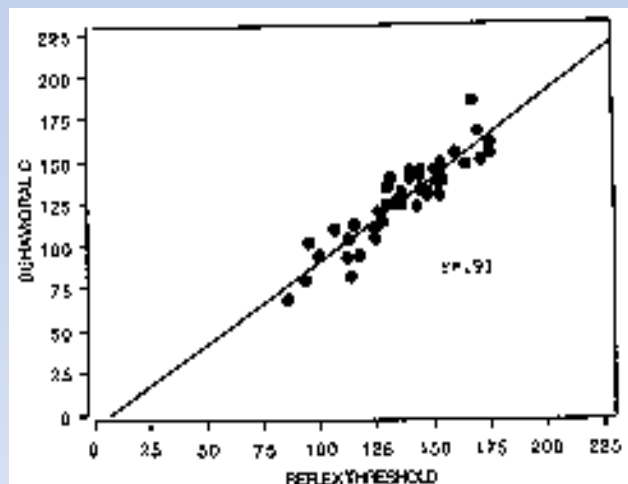


Fig. 2, Hodges et al. (1999)

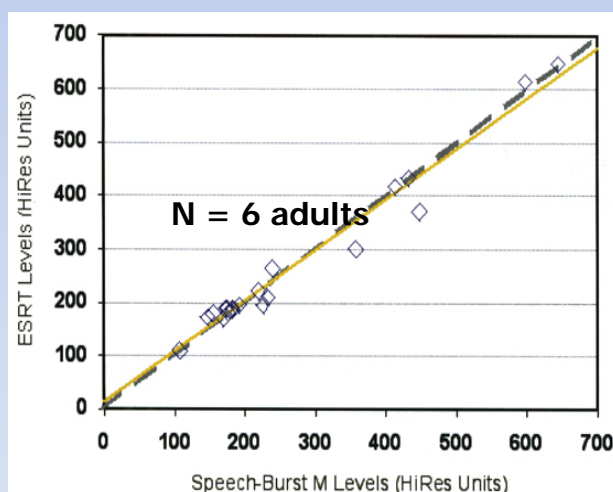


Fig. 1, Buckler et al. (2003)

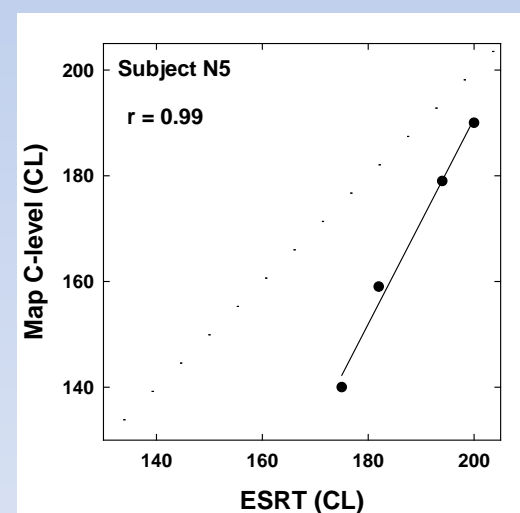


Fig. 6-4, Hughes (2012)

ESRT

- Good to use for young prelingually deafened children who lack the concept of “loud”
- More challenging to measure than ECAP
 - ESRT requires healthy middle ear
 - Recipient must sit still and maintain pressurized seal
 - ESRT measurable in **~65-80%** of CI users (*e.g., Hodges et al. 1999; Caner et al. 2007; Wolfe & Kasulis 2008*)
 - ECAP measurable in **~95%** of CI users (*e.g., Cafarelli Dees et al. 2005; van Dijk et al. 2007*)

Performance

- Speech perception in adults with ECAP-based maps or with ESRT-based maps show similar or slightly poorer performance compared with behaviorally measured maps.

(e.g., Seyle & Brown 2002; Smoorenburg et al. 2002; Hodges et al. 1997; Wolfe & Kasulis, 2008)

Conclusions

- Objective measures offer valuable information when subjective/behavioral feedback is not available.
- Predictive ability is not precise, but can be sufficient enough to provide adequate audibility for speech/language development while children mature.

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